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CONTROLLING HELIOTHIS SPP ON COTTON THROUGH THE RELEASE OF TRICHOGRAMMA PRETIOSUM AND APPLICATIONS OF BACILLUS THURINGIENSIS
AN ECONOMIC ASSESSMENT

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ABSTRACT

This study examines the cost effectiveness of employing biological controls to control Heliothis spp. on cotton in the Delta Area of Mississippi. The biological controls examined are: a) the release of Trichogramma, an egg parasitoid, b) the use of Bacillus thuringiensis, a bacterial agent, and c) the joint use of Bacillus thuringiensis and Trichogramma. The cost of employing the biological agents are compared to the cost of employing conventional material, and break-even yields are determined. Partial budget analysis indicates that the cost of utilizing Trichogramma or Bacillus thuringiensis as the control agent may be cost competitive. Further research is needed to determine the yield effects of the biological controls examined in this study before use recommendations can be made.

Key words: Partial budget analysis, Biological controls, cotton insect pest control, Mississippi Delta, Trichogramma, Bacillus thuringiensis, Heliothis spp.

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CONTENTS

HIGHLIGHTS

The control of the tobacco budworm and the cotton bollworm on cotton, in the Delta Area of Mississippi, constitutes over 80 percent of the insect control costs in that region. The cost of controlling these two pests with strategic releases of Trichogramma, a parasitic wasp, Bacillus thuringiensis, (B.t.) a bacterium pathogen, and the combined use of these two agents in an integrated framework, is compared with the cost of controlling these pests with current, conventional controls. Since it's assumed that the other inputs of production are independent of the insect control strategy, partial budget analysis is used to determine break-even yields.

Given the assumption that the relative species abundance is constant for all strategies, the analysis indicates that the use of Trichogramma or B.t, as the control agent may be cost competitive. To maintain the same net returns as conventional controls, growers who utilize B.t. must experience a yield increase of six pounds per acre. Growers who employ Trichogramma as the control agent can either absorb a yield decrease of up to 50 pounds per acre, or must increase yield by four pounds per acre, depending upon the assumption made for release rate and price of Trichogramma. Break-even yields for the integrated use of B.t. and Trichogramma range between an increase of three pounds to an increase of 86 pounds per acre, depending upon the release rate and price for Trichogramma. For the state of Mississippi, the standard deviation of yield, between 1972 to 1978, was 100 pounds, which seems to indicate that the yield changes discussed are possible.

Due to the lack of data relating cotton yields to the alternative control strategies examined, this analysis can not be utilized for control recommendations.

INTRODUCTION

The use of insecticides in crop protection has caused considerable contorversy because of possible adverse effects upon the environment and to human health. In a world where the agricultural land base is decreasing while the population is increasing, the protection of crops from losses due to insects and other pests is mandatory in order to feed the expanding population. Researchers therefore, are examining alternative methods for protecting a crop while minimizing the possible adverse effects associated with the majority of the current chemicals. One crop-pest complex which has received attention is the control of Heliothis spp., (the cotton bollworm and the tobacco budworm), on cotton.

The control of insect pests on cotton has traditionally required more insecticides than has the control of pests on any other crop. To prevent losses from insects, cotton growers spent $207 million in 1978 (9) [1]. Despite this attempt to prevent losses, insect pests still caused damage estimated at almost 7 percent of production (8). The major culprits are two species of Heliothis tobacco budworm (H. virescens) and bollworm (H. zea). In 1976, almost 26 million pounds active ingredients (a.i.) of insecticides were applied to cotton primarily to control these pests. In contrast, 7.9 and 7.2 million pounds were used to control insect pests of soybeans and wheat, respectively (30).

This reliance on chemicals for suppression of insect populations has led to the development of resistant population strains. Given current technology, future control will require higher levels of insecticides. In addition, the environmental and human health hazards of using chemicals have become a subject of concern for many people. Consequently research has been underway to develop

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1/ Underscored numbers in parenthesis refer to citations listed as literature cited, page .

alternative methods of controlling insect pests, including Heliothis, to minimize the use of conventional chemicals. Two such alternatives are the release of wasps, Trichogramma spp., which parasitize Heliothis spp. eggs, and application of the delta-Endotoxin produced by the bacterium Bacillus thuringiensis.

The objectives of this report are:

1. to present a brief synopsis of cotton production, insecticide use, cost of control, and losses due to insect pests,

2. to develop a cost of control budget for various Trichogramma regimes,

3. to develop a cost of control budget for a Bacillus thuringiensis regime,

4. to develop a cost of control budget for the use of Trichogramma and Bacillus thuringiensis in a control regime.

5. to compare alternative regimes on the basis of break-even analysis.

The control regimes examined in this report are assumed to provide the same level of protection, that is, yields do not change. This assumption is made because currently, little information is available on expected cotton production from controlling Heliothis with conventional chemicals compared to controlling Heliothis with Trichogramma releases or Bacillus thuringiensis applications. A pilot test in 1978 would have generated some of these data, but it was not completed. The participating farmer, in mid-season, decided to withdraw his cooperation. Consequently, partial budgets were developed for the various control techniques. Break-even analysis was performed to examine the yield changes required to bring about equal control costs among the alternatives. The effects of changing the price and release rate of Trichogramma also are presented.

Background

In this section, the value of cotton production, the volume of insecticides used, the cost of control, and losses of production from key insects pests

are presented. The purpose is to provide the reader with an overview of the magnitude of the insect control problems associated with the production of cotton.

Cotton Production

Cotton production is an important component of American agriculture. In 1978 there were 12.4 million acres of cotton harvested in the United States, producing 10.9 million bales of lint (28). Table 1 presents cotton acres harvested, yield and total production for 1978, by state and region. The cash receipts of $3.0 billion generated by cotton production in 1978 made cotton the eight leading agricultural product. If livestock products are excluded, it is the fourth highest generator of cash receipts (32). Cotton also is an important export commodity. In 1977, 5.2 million bales of cotton were exported, valued at $1.7 billion dollars (25).

Insecticide Usage and Cost of Control

The production of cotton has required the use of insecticides for the control of various insect pests in order for it to be grown profitably. In 1976, 64.1 million pounds active ingredients (a.i.) of insecticides were used by cotton growers (30). This represents 49 percent of the total quantity of insecticides used on all crops that year. The insecticide volume used on cotton was more than double the amount used on corn, the second leading crop in the utilization of insecticides. Over 7 million acres, or 61 percent of the total cotton acres in 1976, were treated with insecticides. Cotton ranked second, behind tobacco, in the percent of the total acres treated. Each treated acre received an average of 9 pounds (a.i.) (30).

Cotton growers, in order to prevent the losses due to insects, spent $162 million in 1975 (31). On the average, this amounts to approximately $18.00 per acre. The expenditures for insect control in 1975 ranged from $.50 to $90.00 per acre. The total insect control costs as a percent of the total

Table 1--Area harvested and yield per acre for all cotton by major producing states 1978.

Region and State	Acres harvested	Yield per acre	Total production	Percent of total U.S. production
	1,000 acres	b. of lint	1,000 bales	Percent
Southeast				
Alabama	315.0	443	291.0	2.7
Florida	3.6	507	3.8	1/
Georgia	115.0	463	111.0	1.0
South Carolina	98.0	562	115.0	1.1
Subtotal	531.6		520.8	4.8
Appalachian				
North Carolina	42.0	514	45.0	0.4
Tennessee	230.0	490	235.0	2.2
Virginia	.1	480	.1	1/
Subtotal	272.1		280.1	2.6
Delta				
Arkansas	760.0	417	660.0	6.1
Louisiana	510.0	450	478.0	4.4
Mississippi	1150.0	575	1378.0	12.7
Subtotal	2420.0		2516.0	23.2
Southern Plains				
Oklahoma	585.0	291	355	3.3
Texas	6228.0	294	3818.6	35.2
Subtotal	6813.0		4173.6	38.5
Mountain				
Arizona	572.2	941	1121.7	10.3
Nevada	1.3	554	1.5	1/
New Mexico	122.7	446	114.0	1.1
Subtotal	696.2		1237.2	11.4
Pacific				
California	1455.1	640	1940.1	17.9
Cornbelt				
Missouri	182.0	496	188.0	1.7
U.S. Total	12,370.0	421	10,855.8	100

1/ Less than 0.1 percent

Source: Crop Production January 1980 USDA/ESCS.

variable costs, ranged from less than 1 percent to a high of 36 percent (table 2). In 1978, insecticide expenditures by cotton producers were $207 million (10). This averages to $16.97 per harvested acre.

Losses Due to Insect Pests

In spite of this heavy reliance on chemicals, insect pests are still damaging the cotton crop. One study determined that even with treatment insect pests annually cause a 19 percent decrease in yield (29). Another study (20) concluded that the withdrawal of chemical insecticides from cotton production would increase losses by an additional 20 percent. A more recent study (8), however, indicates, that with current control, the loss from insect pests is only 6.6 percent. Table 3 contains the estimated percent yield loss from insects by states (8). This table shows that in seven states (with 31 percent of the total cotton acreage), losses were greater than 11 percent. Thus, insect pests present a significant problem to cotton growers. In spite of increased control efforts and expenditures, insects are still causing substantial damage.

Two Key Pests

There are more than 100 species of insects considered pests of cotton, but relatively few cause significant annual losses on a frequent basis. By far, the most serious insect pests of cotton are the boll weevil and *Heliothis spp.* bollworms and tobacco budworms. These insect pests accounted for 63 percent of the losses in one study (29) and 85 percent of the losses in another study (8).

The fact that the *Heliothis* complex and the boll weevil are the major insect pests of cotton is further substantiated by preliminary data from the 1976 USDA Pesticide Use Survey (30). Of the total quantity of insecticides used on cotton in 1976, almost 26 million pounds were used primarily to control *Heliothis* and almost 24 million pounds were used to control boll weevils.

State	FEDS AREA	Acres Represented	Yield	Insecticide Material		Custon applications		Total Insect Control	Total Variable Cost (TVC)	Insect Cost As % of (TVC)	Insect Cost per Pound
		1,000	lbs.	$/Acre	No.	$/Acre	No.	$/Acre	$/Acre	Percent	Dollars
Oklahoma	300	269.7	203.2	1.66	.06	1.98	.2	0.50	60.69	.8	.002
Texas	200	1420.4	262.8	2.62	.15	2.00	.06	0.51	91.70	.6	.002
Texas	300	80.0	367.8	1.70	.8	2.00	.62	2.60	122.81	2.1	.01
Texas	900	384.9	184.0	2.36	2.8	1.50	1.0	8.11	62.85	12.9	.04
California	500	845.0	1042.0	3.65	2.0	3.75	1.5	12.93	272.79	4.7	.01
Arkansas	300	383.6	489.0	3.47	5.5	2.00	1.0	21.08	141.63	14.9	.04
Mississippi	300	45.2	280.0	2.21	10.0	1.65	7.0	33.65	147.11	22.9	.12
Arizona	200	2528.0	1050.0	2.95	9.4	1.75	7.1	40.15	347.45	11.6	.04
South Carolina	100	47.4	456.9	3.41	14.0	--	--	47.74	194.19	24.6	.10
Texas	600	55.9	456.1	3.73	9.6	2.00	8.0	51.81	206.65	25.1	.11
Mississippi	100	712.5	443.0	4.39	10.0	1.65	9.5	59.57	187.82	31.7	.13
Georgia	500	57.3	409.2	3.41	16.0	2.00	8.0	70.56	220.95	31.9	.17
North Carolina	State	56.0	390.3	4.00	15.0	1.85	8.0	74.80	208.21	35.9	.19
Georgia	400	75.7	515.2	4.59	14.0	2.00	8.1	80.46	240.13	33.5	.16
South Carolina	200	45.7	467.5	3.93	15.0	2.00	15.0	88.95	228.91	38.9	.19
California	700	54.6	1043.0	5.25	10.0	3.75	10.0	90.00	363.63	24.8	.09

Source: USDA, CEO-ESCS Firm Enterprise Data Systems Crop Budgets. 1976.

:ble 3--Cotton: percent yield loss from insects by State

:ate	Boll weevil	Budworm/ bollworm	Pink bollworm	Others	Total
			Percent		
.abama	2.4	11.8	0	4.2	18.4
:izona	0	0.5	1.25	1.1	2.85
·kansas	1.54	3.0	0	0.46	5.0
ılifornia	0	0.04	0.37	0.28	0.69
›orgia	2.4	8.4	0	1.2	12.0
›uisiana	6.73	12.52	0	1.0	20.25
ssissippi	3.4	9.1	0	2.3	14.8
issouri	0.3	1.6	0	1.0	2.9
›w Mexico	0	2.4	0.1	2.5	5.0
›rth Carolina	6.4	8.6	0	0	15.0
‹lahoma	7.1	3.6	0	1.0	11.7
›uth Carolina	4.4	11.4	0	1.7	17.5
›nnessee	2.4	0.4	0	0.38	3.18
›xas	2.35	0.78	0.01	0.91	4.05
Total U.S.	1.94	3.67	0.09	0.89	6.6

›urce: DeBord, Donald V., "Cotton Insects and Weed Loss Analysis."

The control of these two pests accounted for 77 percent of the total quantity of insecticde used on cotton (tables 4 and 5).

ALTERNATIVE CONTROLS

This reliance on insecticides has created several problems for cotton growers and the general populace. The public is concerned about the impact insecticides may have on the environment and public health. Some insecticides are suspected of being carcinogenic. There is also concern that the persistent nature of some of these compounds may lead to long-term adverse effects on human health.

From the growers' standpoint there is uncertainty about the future availability of some key insecticides due to regulatory actions [2/]. Furthermore, the effectiveness of current control practices is being questioned because of resistance buildup [3/], resurgency [4/], and secondary pest outbreaks [5/].

2/ Based on the Cotton Preassessment Report (28), of the 22 insecticides judged by the experts to be important in the production of cotton, 12 are in danger of being withdrawn from the market.

3/ Since 1947, 25 species of insects and spider mites that attack cotton are known to have developed resistance (31). In addition, a study by Carlson (7) determined that the long run marginal productivity of insecticides has decreased because of the development of resistance.

4/ Refers to a situation where the use of insecticides not only suppresses the pest population but also kills beneficial insects. This allows subsequent generations of the pests to increase at a faster rate, creating additional need for insecticides.

5/ Refers to a situation where the use of insecticides aimed at a target pest, by killing beneficial insects, results in the outbreak of other nontarget pests which require control.

Table 4--Extent of use of insecticides to control target insects on cotton (acre treatments), 1976 1/

Chemical	Boll weevil	Bollworm/ Budworm	Pink Bollworm	Other	Total
		Percent			
Toxaphene	44	39	10	7	100
Methyl parathion	43	39	9	9	100
EPN	20	58	0	22	100
Galecron	7	69	20	4	100
Azodrin	41	8	17	34	100
Endosulfan	60	40	0	0	100
Parathion	10	41	48	1	100

Based on 1976 Pesticide Usage Survey, Crop Reportin Board, SRS, USDA, preliminary data Nov. 14, 1977.

1/ Example: Of all the cotton acres exposed to Toxaphene, 44 percent utilized the chemical to control the boll weevil.

Table 5--Pounds of active ingredients of selected insecticides used for the control of target cotton insects, 1976

Chemical	Boll weevil	Bollworm/ Budworm	Pink bollworm	Others	Total	
	-----------	-----------	1,000 lbs.	-----------	-----------	Percent
Toxaphene	11,567.2	10,252.7	2,628.9	1,840.4	26,289	41
Methyl parathion	8,591,8	7.792.6	1,798.3	1,798.3	19,981	31
EPN	1,228.0	3,561.0	0	1,351.0	6,140	10
Galecron	310.6	3,061.6	887.4	177.5	4,437	7
Azodrin	609.7	119.0	252.8	505.6	1,487	2
Endosulfan	406.2	270.8	0	0	677	1
Parathion	68	278.8	326.4	6.8	680	1
Other	784.1	658.8	224	3,175.7	4,342	7
Total	23,565.4	25,985.3	6,117.8	8,855.3	64,524	
Percent	37	40	9	14		100

Based on 1976 Pesticide Usage Survey Crop Reporting Board SRS, USDA, preliminary data Nov. 14, 1977, and table 4. It is assumed that there is a one to one relationship between percent of insecticide acre treatments by chemical on target insect and the total quantity used on that insect.

Because of these concerns, along with the high cost of control, researchers have tried to develop alternative insect control regimes. The alternatives include the use of field scouts for timing the application of insecticides, (based on a "damage threshold"), the use of cultural techniques, short season and resistant plant varieties, genetic modification of pests, pheromones, growth regulators, and biological controls—use of microbial agents, and importation or augmentation of natural enemies.

The implementation of these alternatives for Heliothis control on cotton has received considerable research attention due to the relatively heavy insecticide load of the current control regime. Two possible agents for Heliothis control are the release of a parasitic wasp, Trichogramma, and the use of a bacterium Bacillus thuringiensis (B.t.). Both of these agents are felt to be environmentally safe because they are host specific.

Trichogramma

Trichogramma is an egg parasite of lepidopterous insects. The female searches for host eggs into which to deposit her eggs. On the average, two parasites emerge from each parasitized host egg (13). The average life cycle of Trichogramma is ten days.

The parasite occurs naturally in many parts of the Cotton Belt, but its population seldom reaches densities necessary to prevent damage. Given current production practices, it appears the use of Trichogramma as a Heliothis control agent requires mass rearing and releasing of the parasite in order to augment [6/] the naturally occurring population.

6/ The augmentation strategy for insect control is the periodic increase of either the number of parasites or predators or the supply of their food to assure that their population levels are adequate to give a desired level of control (21).

Augmentation of natural predators and parasites as an insect control strategy has been implemented successfully in the Filmore Citrus Protective District in Ventura County, California, for the control of citrus pests. USSR, China, U.K., Netherlands, France, Mexico, Brazil, Venezuela, and West Germany have successfully produced and released parasites and predators for the control of various pests (16).

The use of Trichogramma in an insect control regime on a variety of crops has been ongoing for some time in the United States and in other countries. Over 3 billion are released annually to control lepidopterous insects on various crops in this country (23). Mexico rears 28 billion annually. Trichogramma is used on 18.5 million acres in the USSR and on 1.7 million acres of cotton in China (23).

Trichogramma presently is available for commercial use on cotton, and many researchers are involved in studying this parasite. In College Station, Texas, scientists have studied the effectiveness of Trichogramma in parasitising Heliothis in the laboratory as well as in the field (24), have examined ways to mass produce the parasite more efficiently (10, 13, 14, 15, 17,) and have studied how to release the parasite mechanically over large areas (2, 6, 10, 11). However, the cost effectiveness of using Trichogramma has not yet been examined.

The use of Trichogramma as a control agent has a number of theoretical assets which must be explored. Trichogramma is density dependent. It will therefore increase and decrease in population as Heliothis increase or decrease. The parasite is mobile. It can be expected, therefore, to locate the higher infestation areas, thereby providing control where it is most needed. Finally, the probability that Heliothis will develop resistance to Trichogramma is very remote.

Bacillus thuringiensis (B.t.)

Bacillus thuringiensis produces an endotoxin which is toxic to lepidopterous larvae. It is available in many formulations and it is applied in the same manner as conventional insecticides. B.t. is registered for use on many crops, including cotton, and it is marketed under a variety of brand names. B.t. kills the larvae within a few days after injestion. Unlike conventional chemicals, however, B.t. is not detrimental to the beneficial species (22). Consequently, it can be used as a part of an augmentation strategy.

In summary, the biological possibility of using Trichogramma and B.t. to control Heliothis has been demonstrated. The economic feasibility of these two control agents, however, remains to be determined. This issue is examined in the following sections.

Method and Basic Assumptions of Analysis

In order to determine whether the use of Trichogramma and/or the use of B.t. is competitive with the use of current insecticide material, the private plus social costs of each strategy must be computed. By adding information on the expected yield of cotton due to the use of a particular technology, the net returns from a control regime can be determined. If the net returns from using Trichogramma and/or B.t. are equal to, or higher than, the net returns from the use of conventional chemicals, then they are competitive, and growers can be expected to switch to the new technology.

Unfortunately, quantitative data on the social cost of using these techniques are not available. Furthermore, expected cotton yields due to the use of Trichogramma or B.t. are lacking, as is information on the relationship between the alternative control strategies and the level of other inputs of production. Consecuently, it is assumed that Trichogramma releases, B.t., and current controls provide the same level of protection. As a result, cotton yields

are expected to be equal in each case. In addition, the analysis only computes the direct private costs of each control strategy at the farm level. The level of the other inputs of production is assumed to be constant and equal for all strategies.

None of the control schemes are expected to affect the quality of cotton. Cotton prices, therefore, will be the same. By assumption, yields are also equal; consequently, the gross revenue associated with each control strategy will be the same. Therefore, in determining the net revenue of each regime, only the cost of control may differ. This analysis concentrates on the cost of control. In addition, when the cost of control differs among the strategies, yield changes necessary to equate net revenues are presented.

It was mentioned earlier that the insect pest structure in cotton is different across the Cotton Belt. Since Trichogramma and B.t. are highly specific control agents, they will be considered in areas where Heliothis control is a major problem. Based on the geographic distribution of Heliothis and Table 3, the potential areas are: Alabama, Georgia, Louisiana, Mississippi, North and South Carolina, and some parts of Texas. In 1978, these areas harvested about 2.4 million acres of cotton—about 19 percent of the national total.

In order to conduct the cost analysis, detailed cost information is needed. The total cost of control is provided by the Firm Enterprise Data Systems (FEDS) Budgets (31). Additional information needed is: the share of the total cost attributable to Heliothis control, along with the variation of the control costs due to different infestation levels of Heliothis. Since the FEDS Budgets do not provide this type of information, it is not possible to analyze the impacts of the alternative strategies on the entire candidate acreage.

Consequently, the Delta area of Mississippi (area 100 in table 2) was selected as a representative area. This area fulfills the requirements of high insect control costs, *Heliothis* control is the major component of costs, cotton production is a very important component of agriculture, and data are available on the composition of the total insect control costs. Information is also available on the cost of controlling different *Heliothis* infestation levels.

ANALYSIS

Conventional Control

The following insect control strategy is representative of control practices used by the majority of the growers in the Delta area: .3 pound of Aeldicarb, (Temik ®) at planting, one application of .2 pound Monocrotophos (Bidrin®) for early season control, and anywhere from 6 to 13 applications of EPN plus methyl parathion with 2 additional applications of .45 pound methomyl (Lannate®) for late season control (20). The majority of applications are aimed at *Heliothis*. Table 6, gives the insect control costs for the three infestation levels. (20). The cost of control ranges from $32.28 per acre for years of light pest infestation to $75.01 per acre when there is heavy pest infestation. The probability of the different pest infestations has been estimated by David Parvin 6/ to be 0.3, 0.4, and 0.3 for light, stardard and heavy pest infestation levels, respectively. The average annual cost for a typical grower can be computed by multiplying the control cost of the infestation level by the probability of occurrence. Table 7 contains the results. On the average, growers in the Delta area can expect to pay $52.38 per acre per season. In particular, a grower (on the average) can expect to make ten applications per season and spend $45.12 per acre to control *Heliothis*.

7/ Personal communication.

Table 6--Conventional insect control costs per acre-Delta area of Mississippi

Item	$/Acre
I. Current controls	
(A) Light insect pressure	
.3 pound Temik at planting	1.45
.2 pound Bidrin early season control	0.84
application cost - ground	1.26
.6 pound EPN plus .6 pound methyl parathion - 10 times	19.80
application - 6 times	6.00
labor cost - 6 times	.18
scouting	3.75
Total	33.28
(B) Standard insect pressure	
Costs	
.3 pound Temik at planting	1.45
.2 pound Bidrin early season control	0.84
application cost per pound	1.26
.6 pound EPN plus .6 pound methyl parathion - 10 times	33.00
application cost - 10 times	10.00
labor cost - 10 times	0.30
scouting	3.75
Total	50.60
(C) Heavy insect pressure	
Same as standard	50.60
plus .6 pound EPN plus .6 pound methyl parathion -3 times	9.90
application - 3 times	3.00
labor cost - 3 times	.09
.45 pound lannate - 2 times	8.16
application - 2 times	3.30
labor - 2 times	.06
Total	75.11

Source: Parvin, D. W. and others, "Budgets for Major Crops, Delta of Mississippi" 1978

Table 7--Conventional average cost of control per acre

Infestation level	Total cost of control	Cost of *Heliothis* control	Applications	Probability of occurrence	Column 1 times Column 4	Column 2 times column 4	Column 3 times column 4
	------$/Acre----		Number		------$/Acre-----		Number
Light	33.28	25.98	6	.3	9.98	7.79	1.8
Standard	50.60	43.30	10	.4	20.24	17.32	4
Heavy	75.11	67.81	15	.3	22.53	20.34	4.5
Total				1.0	52.75	45.45	10.3

Trichogramma Regime Control Costs and Breakeven Yields

In order to obtain the per acre cost of controlling *Heliothis* with *Trichogramma*, the following assumptions were made:

1. The price of *Trichogramma* is $.08 per thousand, the average price reported by commercial insectaries.
2. Three *Heliothis* generations occur on cotton. The per acre strategy for effectively controlling *Heliothis* is to make three releases over a 9-day interval of 50,000 parasites per release for each generation of *Heliothis* 8/.
3. The labor and application costs for *Trichogramma* are assumed to be 33 percent and 10 percent higher than for conventional control, respectively, because of the delicate nature of the parasite and the need to handle it carefully. For example, to insure that the maximum number of parasites emerge in the field, *Trichogramma* must be conditioned by variations in temperature. In addition, special care is needed when transporting the parasite from storage to the field for application.
4. For aerial applications, *Trichogramma* is mixed with 5 pounds of bran per acre per release. The bran costs $.04 per pound.
5. The current practice of using Temik® and Bidrin® for early season control is maintained.
6. The *Trichogramma* release strategy is independent of the pest infestation level.

8/ The *Trichogramma* release strategy reported is based on the control scheme outlined in a pilot project proposal that would have been tested in 1978. The participating grower, however, decided to withdraw his cooperation during mid-season, thereby terminating the experiment.

7. Scouts are used in the Trichogramma release strategy to monitor egg laying and determine time of release. The cost is assumed to be $3.75 per acre, which is the same as scouting cost for conventional controls.

Based on these assumptions, insect control costs, with Trichogramma as the control agent, are presented in table 8. The Trichogramma pest control strategy is expected, on the average, to cost a grower $55.36 per acre. This is $2.61 per acre higher than the average cost of conventional controls. If the assumption of equal yields is dropped, the use of Trichogramma would have to increase cotton yields by a little over 4 pounds per acre in order to maintain the same income level as that obtained under conventional control. 9/ The 4 pound differential required for breakeven yield is minor commpared to the yearly variation of cotton yields.

Between 1972 and 1978, the average cotton yield per acre for all of Mississippi was 526 pounds, with a standard deviation of 100 pounds per acre. If the assumption of equal level of control is made, the use of Trichogramma campares favorably to the use of conventional controls.

Trichogramma Regime--Varying Assumptions and Breakeven Yield

The use of Trichogramma as a control agent is a relatively new technology. As the research on using this parasite continues, the probability of significant breakthroughs in rearing and releasing will increase. It is conceivable that a more effective parasite will become available, one that can search more area, live longer, and parasitize more hosts. When this happens, the number of Trichogramma needed per release will decrease. In addition,, the rearing of Trichogramma increases and production expands to meet the increased demand, economies of scale may be realized, decreasing the unit price of Trichogramma.

9/ This is based on cotton price of $.52 per pound for lint, a seed price of $.05 per pound, and the relationship that one pound of lint yields 1.55 pounds of seed.

Table 8--Per acre cost of insect control using a Trichogramma regimen.

Item	$/acre
Trichogramma	36.00
Labor cost	9.90
Bran	.36
Scouting	1.80
.3 pound Temik at planting	3.75
.2 pound Bidrin	1.45
Application cost	.84
	1.26
	55.36

1/ 3 applications per generation x 3 generations = 9 applications.
50,000 per application x 9 = 450,000.
450,000 x $.08 per thousand = $36.00

Table 9 presents hypothetical insect control costs under three different release rates and two different pricing schemes.

The average insect control cost of conventional controls was previously calculated to be $52.75 per acre. Comparing this figure with the control costs reported in table 9 reveals that Trichogramma costs less for five of the six different price and release rate combinations. Thus, Trichogramma should be the preferred insect control strategy in those five situations, given the assumption that the different release rates maintain the same level of control and hence identical yields as current conventional controls. This assumption is subject to debate, especially since large scale field data is sparse. Furthermore, there are trade-offs between yield and pest control expenditures which are ignored in the assumption of equal yields. Thus column 5 of table 9 lists the yield changes which together with the specified costs of the three release rates and two price alternatives would just equal the current pest control costs of $52.75 per acre.

Variations in parasite release rate cause a larger variation in the breakeven yield when Trichogramma priced relatively high. For example, changing the numbers per release from 50,000 to 12,000 causes a change in the breakeven yield of almost 46 pounds per acre when Trichogramma is priced at $.08 per thousand. When Trichogramma costs $.03 per thousand, however, the same change in the release rate causes breakeven yields to change by a little over 17 pounds per acre. This is because at the lower price of Trichogramma, the ratio of Heliothis control to total insect control costs becomes smaller.

The trade-off between changing the price of Trichogramma and changing the release rate so that cost is constant also can be obtained. A decrease in the price of Trichogramma from $.08 to $.07 per thousand produces the same control

[illegible] Insect control costs under three different release [illegible] columns.

[illegible] control cost of conventional controls was previously [illegible] 75 per acre. Comparing this figure with the control [illegible] in [illegible] 9 reveals that *Trichogramma* costs less for five of the [illegible] and release rate combinations. Thus, *Trichogramma* should [illegible] insect control strategy in those five situations, given the [illegible] the different release rates maintain the same level of control [illegible] as current conventional controls. This assumption [illegible] debate, especially since large scale field data is sparse.

[illegible], there are tradeoffs between yield and pest control expenditures [illegible] noted in the assumption of equal yields. Thus column 5 of table 9 [illegible] yield changes which together with the specified costs of the three [illegible] and two price alternatives would just equal the current pest [illegible] of $52.75 per acre.

In parasite release rate cause a larger variation in the [illegible] when *Trichogramma* priced relatively high. For example, changing [illegible] per release from 50,000 to 12,000 causes a change in the breakeven [illegible] 46 pounds per acre when *Trichogramma* is priced at $.08 per [illegible] *Trichogramma* costs $.03 per thousand, however, the same change [illegible] rate causes breakeven yields to change by a little over 17 pounds [illegible] is because at the lower price of *Trichogramma*, the ratio of [illegible] control to total insect control costs becomes smaller.

[illegible] between changing the price of *Trichogramma* and [illegible] the [illegible] so that cost is constant also can be obtained. A decrease in the [illegible] from $.08 to $.07 per thousand produces the same control.

Table 9--Insect control costs and bread even yields for three different Trichogramma release rates and two different Trichogramma prices

Price of Trichogramma	Release Rate	Cost of Trichogramma	Total insect control cost	Breakeven Yield
$/000	000/release/acre	$/acre	$/acre	Pounds/acre
	12	8.64	28.00	-41.25
.08	25	18.00	37.36	-26.00
	50	36.00	55.36	4.00
	12	3.24	22.60	-50.00
.03	25	6.75	26.11	-44.00
	50	13.50	32.86	-33.00

Notes:
1. Labor cost, aerial application cost, etc. are assumed to be the same as in table 8.
2. All release rates are assumed to provide the same level of control as conventional material.
3. Release rates are independent of the pest infestation level.
4. The release rates chosen are based on work by Knipling and McGuire (12). They suggest that the range of releases for effective control throughout a growing season is from 12,000 to 50,000 per release.
5. In (23) it is stated that a price of $.03 per thousand is possible.

costs as holding the price constant at $.08 per thousand while decreasing the release rate from 50,000 to 43,750. This indicates that if the resources for Trichogramma research are limited, a higher payoff may be forthcoming by devoting more resources to developing methods of producing the parasite more cheaply rather than concentrating on producing a more efficient parasite. This is especially true in areas where insecticide drift is a problem. In those locations, large releases of the parasite would be needed to offset the expected losses due to drift.

B.t. Regime Control Costs and Breakeven Yield

B.t. is registered for use on cotton and is available for commercial use under a variety of brand names, Dipel® being the most common. A budget of a B.t. regime can be constructed utilizing the following market information and qualifying assumptions:

1. A market price for Dipel® of $8.80 per pound.
2. A recommended rate of .5 pound per acre per application. 10/
3. Nine applications per season. 11/
4. B.t. formulations such as Dipel® are applied in the same manner as conventional chemicals. Dipel® can be mixed in and applied with conventional chemicals. Consequently, labor and application costs of using Dipel® should be the same as the labor and application costs of using the conventional materials.
5. All other insect control costs and practices are the same as conventional.
6. The use of B.t. is independent of Heliothis infestation level.

10/ The strategy delineated would have been tested in the pilot project mentioned previously.

11/ The strategy delineated would have been tested in the pilot project mentioned previously.

The cost of using the B.t. regime, based on these assumptions, is presented in table 10. A grower can expect to pay $56.17 per acre if a B.t. strategy is implemented. This is $3.42 per acre higher than the average cost associated with the conventional control strategy. In order to maintain the same income level per acre associated with conventional chemicals, the use of B.t., therefore, like Trichogramma appears to be relatively cost competitive, given the assumption of equal yields.

Trichogramma plus B.t. Control Costs

Growers may be concerned that the use of either Trichogramma or B.t. alone may not provide adequate control. The use of both agents in a well planned reginem may provide better control of Heliothis. The scenario contemplated under this scheme is to release Trichogramma when Heliothis populations are primarily in the egg stage and follow up, within a couple of days, with the use of B.t. when the eggs hatch. Under this plan,, the two agents reinforce the effectiveness of each other. Trichogramma will parasitize a certain percent of the Heliothis eggs, resulting in fewer larvae appearing in the field. Dipel® will be used to control the larvae without adversely affecting the Trichogramma. In the following generation of Heliothis, the number of eggs laid will be fewer than would have occurred otherwise. This raises the possibility that in subsequent generations the Trichogramma release rate may be lower due to the fewer number of eggs that will be available for parasitization and the larger base of Trichogramma available in the field.

Several possible use combinations of Trichogramma plus B.t. can be developed and their cost of control compared with the costs of conventional control. One possible tactic is to release varying levels of Trichogramma (12,000, 25,000, 50,000 per release) in combination with a fixed rate of .5 pound per application for B.t. The costs are presented in table 11.

ble 10--Per acre insect control using B.t. (Dipel®) for *Heliothis* control

Item	$/Acre
.3 pounds Temik at planting	1.45
.2 pounds Bidrin	.84
Application cost	1.26
.5 pounds Dipel 9 times	39.60
Application cost 9 times	9.00
Labor cost 9 times	.27
Scouting	3.75
	56.17

Given the assumption of equal yields for all pest control strategies, this combination of B.t. and Trichogramma is not cost competitive with conventional control. Relaxing the assumption of equal yields, the combination B.t. and Trichogramma tactics would have to increase yields 31 to 86 pounds of lint and seed per acre, as shown in table 11, to offset the increased pest control costs.

Another possible combination would be to make the release rate of Trichogramma dependent upon the pest infestation level while applying B.t. at a constant rate of .5 pound per acre nine times a season. Assuming the control of heavy infestation requires a release rate of 50,000 standard infestation 25,000 and light infestation 12,000 per release; the long run average control cost, when Trichogramma is priced at $.08 per thousand, is $83.82 per acre, while the cost is $75.95 per acre when Trichogramma is priced at $.03 per thousand (table 12). This combination is also not competitive with conventional control. Yields would have to increase more than 38 pounds of lint and seed per acre in order to maintain the same income level attained with conventional controls.

One of the advantages of Trichogramma and B.t. as control agents is that they control Heliothis without significantly disrupting the natural control provided by predators and parasites. Furthermore, the released Trichogramma can multiply in the field as they provide control. Because of this additional pool of control agents, as the season progresses fewer releases and fewer numbers of Trichogramma per release may be needed. By the same token, fewer applications of B.t. may provide effective control. The cost of this scenario is summarized in table 13. The cost of $64.88 per acre is $12.13 per acre higher than the conventional control cost of $52.75. If the price of Trichogramma is reduced to $.03 per thousand, however, the cost of the scenario outlined in table 13 would be reduced to $54.28 per acre which compares favorably to the cost of conventional controls.

Item	Unit	Conventional control	Dipel plus Trichogramma @ $.08/000			Dipel plus Trichogramma @ $03/000		
			Trichogramma release rate per acre			Trichogramma release rate per acre		
			50,000	25,000	12,000	50,000	25,000	12,000
Total insect control costs	$/Acre	52.75	104.23	86.23	76.87	81.73	74.98	71.47
Yield change needed to maintain income	lbs/acre		85.8	55.8	40.2	48.3	37.05	31.2

Notes: 1. No change in other inputs.
2. B.t. rate of .5 pound per application per acre.
3. Nine Trichogramma releases and B.t. applications per season.
4. Trichogramma release rates constant throughout season.

Table 12--*B.t.* (Dipel) plus *Trichogramma* use scenarios; variable *Trichogramma* release rate based on infestation level

Infestation level	Probability of Occurrence	Unit	Cost of conventional controls	Cost of *B.t.* plus *Trichogramma* @ $.08/000	Cost of *B.t.* plus *Trichogramma* @ $.03/000
L	.3	$/acre	75.11	104.23	81.73
M	.4	$/acre	50.60	86.23	74.98
H	.3	$/acre	33.28	76.87	71.47
Total cost		$/acre	52.75	83.82	75.95
Breakeven yields		lbs/acre	0	52.	39.

Table 13--*Trichogramma* plus *B.t.* scenario, assuming a variable use rate during the growing season

Trichogramma price @ $.08/1000	
Item	$/acre
.3 pound Temik at planting	1.45
.2 pound Bidrin	.84
Application cost	1.26
Trichogramma	16.96
Application cost	6.60
Bran	1.20
Labor	.24
B.t. (Dipel)	26.40
Application cost	6.00
Labor cost	.18
Scouting	3.75
	64.88

Notes: 1. *Trichogramma* release strategies:

3 releases @ 50,000 per release,
2 releases at 25,000 per release, and
1 release of 12,000.

2. 6 applications of *B.t.* at .5 lb. per application.
3. Release strategy independent of *Heliothis* infestation levels.
4. All other inputs remain same.

CONCLUSIONS

A summary of the various control strategies that were examined in this paper is presented in table 14. Given the assumptions of this analysis, it appears that the sole use of either Trichogramma or B.t. is cost competitive with current controls. The control scenarios in which both Trichogramma and B.t. are employed cost considerably more than the conventional control scenario in all instances examined but one. If the assumption of equal yields is maintained, the use of both Trichogramma and B.t. is not cost competitive. If the assumption of constant yields is droped, then the use of both agents requires yield increases of 20 to 86 pounds of lint and seed per acre in order to be as profitable as current controls.

Although the analysis indicates that Trichogramma is a cost competitive method of controlling Heliothis, control recommendations cannot be made because of the number of assumptions that were made to bridge information gaps. For example, some of the cost components of the Trichogramma control strategy may be underestimated. The successful release of Trichogramma requires temperature variation to insure that the wasps do not emerge prior to field releases. This was incorporated into the analysis by increasing the labor and application cost of Trichogramma compared to conventional controls. Information is not available, however, to varify the validity of the increase. The cost of the conventional chemical regime is also underestimated because only the direct private costs are included in the budget. The social costs of using this technology are probably much higher than the cost discussed here because of health hazards and environmental pollution. The addition of social costs would improve the competitiveness of the biological agents because they do not impose such costs upon society.

Table 14--Summary of strategies

Control strategy	Cost of control	Breakeven yield
	($/acre)	lbs./acre
1. Density dependent conventional controls	52.75	0
2. Trichogramma		
@ $.08/1000		
12,000/release	28.00	-41
25,000/release	37.36	-26
50,000/release	55.36	4
@ $.03/1000		
12,000/release	23	-50
25,000/release	26	-44
50,000/release	33	-33
3. B.t.	56	6
4. Trichogramma plus B.t.		
@ $.08/1000		
12,000/release	77	40
25,000/release	86	56
50,000/release	104	86
@ $.03/1000		
12,000/release	71	31
25,000/release	75	37
50,000/release	82	48
5. B.t. plus density dependent Trichogramma releases		
@ $.08/1000	84	52
$.03/1000	76	39
6. B.t. plus Trichogramma; variable use rate within a season		
@ $.08/1000	65	20
@ $.03/1000	54	3

Growers, in choosing among control technologies, are interested in maximizing income, not in minimizing the cost of insect control. The strong assumption of equal yields for all control alternatives was made necessary due to the lack of information on the effectiveness of the various control schemes. The expected yield of lint and seed from following a prescribed control strategy is not known at this time.

The analysis only examined the short run costs of control. There are long run implications of the alternatives which may change their ralative desirability. Conventional chemicals, for example, only provide temporary control. They must be employed regularly in order to suppress the insect population level. This constant pressure implies that only the resistant strains of the insect will survive and multiply. In the future, therefore, higher quantities of the chemical will be required to achieve a given level of control.

Biological agents such as *Trichogramma*, on the other hand, do not suffer from this problem with resistance. The release rates which were examined would not have to be increased in the future in order to achieve the same level of control as is achieved today. It is conceivable that the release rate could decrease as the population levels of the naturally occurring beneficial insects build up over time.

Finally, the analysis is based on a short run, static presentation of what is a dynamic system. In order to obtain a better indication of the relative effectiveness of the various alternatives, the analysis must move beyond the examination of partial budgets. For example, this analysis implicity assumed the same insect population structure for the alternative controls. This assumption most likely is false. The biological agents are host specific; they will only control *Heliothis*. If there is an outbreak in the population level of other pests such as lygus bugs, cotton leaf perforators, chemicals will be needed.

This will increase the cost of control, along with destroying the effectiveness of the biological agents. On the other hand, conventional chemicals are broad spectrum, killing insect pests as well as beneficial insects. This may increase the probability of secondary pest outbreaks and resurgence, thereby increasing the cost of control. How these factors affect the cost of control of the strategies is not known at this time.

To summarize, given the information that is available, the relative effectiveness of the control strategies can not be accurately assessed. The costs presented in this report will change as the data gaps are filled in the future, possibly changing the relative ranking of the controls. Although it is not possible to determine the best control technology, this analysis identifies data that are needed to determine the relative effectiveness of controls so that recommendations can be made in the future. The analysis also provides preliminary information on the cost of an effective Trichogramma control regime that is cost competitive at the farm level.

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